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Foreword

As the nation moves into the 21st century, there is a growing need for cheaper, more available access to space. AEDC is firmly positioned to support this need through our simulated-altitude rocket test and evaluation capability.

Today, AEDC has an unprecedented capability for testing and evaluating rocket engines under simulated altitude conditions. To meet the growing test requirements resulting from increased use of liquid-propellant space boosters, the center returned to testing large liquid storable and cryogenic-propellant rocket engines after a hiatus of nearly 20 years. We played a key role in keeping the Titan IV, Americaís only expendable, heavy-lift launch vehicle, from being grounded by qualification testing a new Stage II engine nozzle and are currently testing the next-generation RL-10 engine. AEDCís newest rocket facility, J-6, significantly expands our capability to test the large and detonable solid rocket motors that will extend the life of the existing ICBM force through 2020.

AEDC is expanding its use of teaming arrangements with rocket developers, resulting in a greater range of services and increased responsiveness. For example, a teaming arrangement between AEDC, the Air Force Space and Missiles Systems Center, Lockheed Martin, Aerojet, TRW, Brown & Root, and a host of smaller contractors accomplished the complex facility preparations and test program for the Titan IV engine test program. Similarly, the first test program using the new cryogenic propellant system also involved similar teamwork. In each case, the teaming arrangement allowed its members to contribute their expertise and resources to ensure a more comprehensive, faster test program to fit the customerís needs.

True to our vision of being the center of knowledge for simulated-altitude rocket testing, we completed a number of initiatives to improve the scope and quality of the products available to our users. These include: statistical analysis of aging trends in solid rocket motors, hosting the Minuteman Propulsion System Rocket Engine database, advances in liquid rocket engine health monitoring, and improved test information handling, storage, and retrieval.

AEDC is taking advantage of this period of growth and expanding horizons to continue as the test center of choice for simulated altitude rocket testing well into the next century.

Col. Robert W. Chedister, AEDC commander

Why Test at Altitude?

Upper-stage rocket motors and engines can behave and perform differently depending on their flight environment. Testing upper-stage rocket propulsion systems is accomplished by either ground test or flight test.

Usually, ground testing leads flight testing and then, once a system is operational, ground testing supplements flight testing. Typical rocket ground test programs include development, qualification, flight proofing, production quality assurance, aging and surveillance, and anomaly investigation.

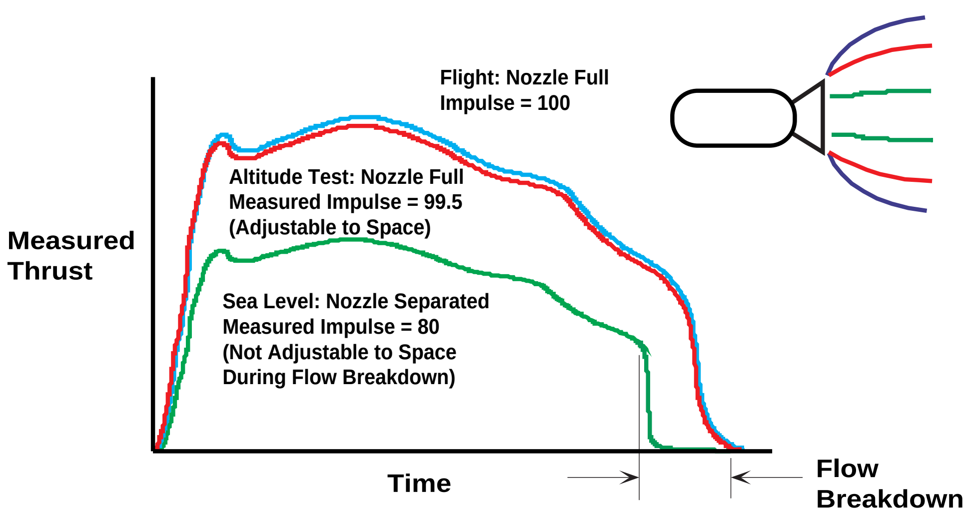
Selecting the ideal method for a particular test is a trade off between cost, risk and desired outcome. At one end of the spectrum, ground testing upper-stage systems at ambient pressure and temperature conditions provides data at the lowest cost. However, the test article must be altered and performs in an unrealistic environment, which can compromise test objectives.

Flight testing, which provides the most realistic conditions, is at the other end of the spectrum. The trade off is high cost, risk to the entire vehicle and payload, telemetry limitations in data quality and quantity, and the inability to recover the test article following the test for analysis. In the middle of the spectrum lies simulated altitude ground testing.

Ground testing upper stage rocket propulsion systems at simulated altitude pressure conditions accurately replicates their flight environment. Significant differences in system performance at simulated altitudes as opposed to ambient conditions include:

Benefits of Altitude Testing

- NO RISK TO FLIGHT VEHICLE
- LOWER COST
- BETTER INSTRUMENTATION
- CLOSE OBSERVATION
- RECOVERABLE CASE/ENGINE/NOZZLE
- REALISTIC IGNITION
- MORE ACCURATE IMPULSE
- BETTER FIDELITY FOR DURABILITY ASSESSMENT



Key Performance Objectives

1. High area-ratio nozzle behavior
2. System thrust and impulse
3. Heat transfer characteris-tics of both engine and vehicle base regions
4. Thrust vector control performance
5. Ignition start transients
6. Plume characteristics

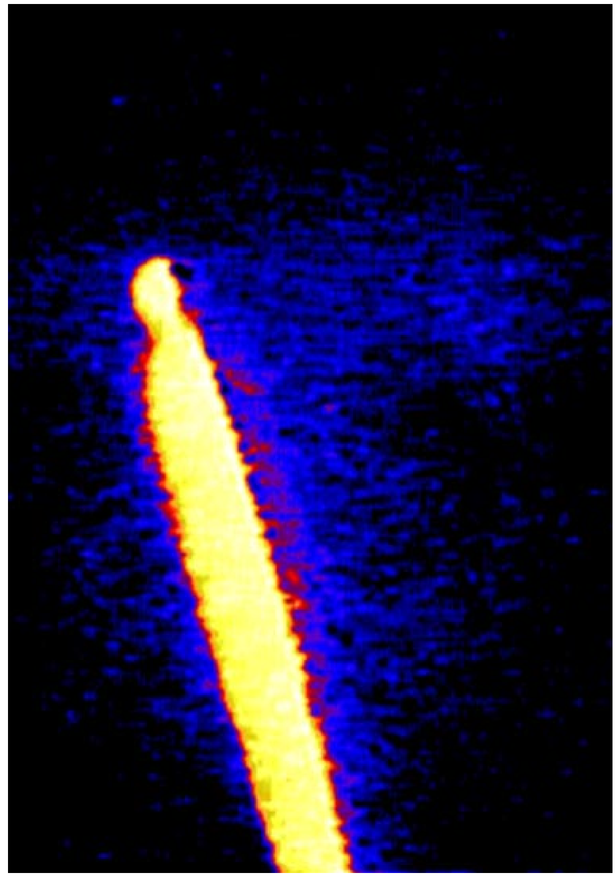
For example, upper stage propulsion systems are optimized for increased performance with large area-ratio nozzles. Simulated altitude testing for these systems is required to flow the nozzle "full," which provides accurate thrust and specific impulse measurements.

Attempting to test at ambient (sea-level) conditions not only compromises engine performance data, but can jeopardize the structural integrity of the nozzle by imposing severe dynamic loads and thermal stresses from nozzle flow separation. Sea-level testing with truncated nozzles does not evaluate nozzle structural integrity and, furthermore, requires test data be adjusted to calculate full-nozzle and thrust vector control systems performance.

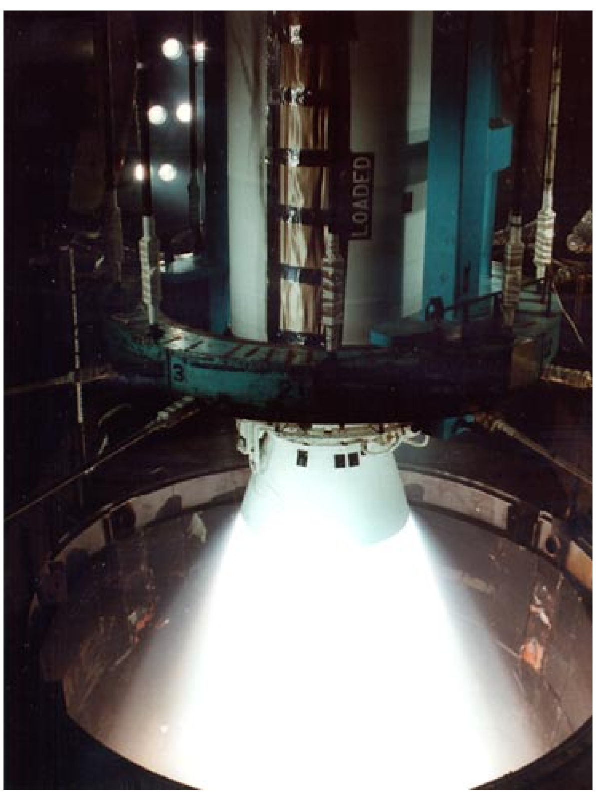
Advantages of ground testing under simulated altitude conditions include carefully-controlled test environments with extensive instrumentation and photographic coverage to determine the operability and performance of a test article. Ground testing can include an extensive array of sophisticated rocket diagnostic instruments obtainable only in a ground test configuration. State-of-the-art techniques such as wide band radiometric infrared and ultraviolet coverage, emission/absorption detection, laser -induced fluorescence plume surveys, and real-time radiography are just some of the typical applications frequently used.

Using a combined simulated-altitude ground test and flight test approach can mitigate program risk with reduced cost and greater understanding of true system performance.

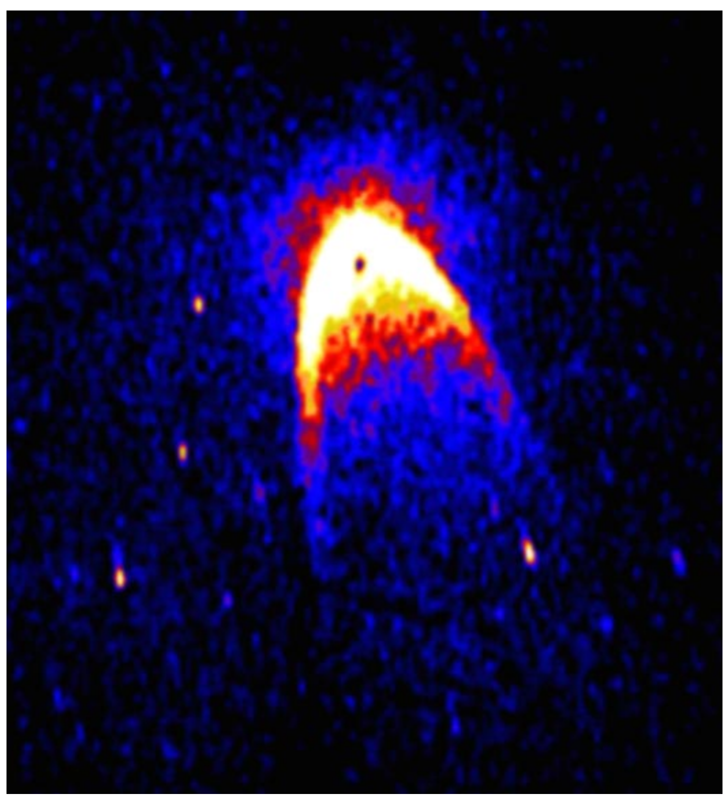
All three techniques have benefits, but the synergism of using them in a well balanced integrated test program yields multiple dividends over the system's life cycle.



Flight rocket plume at low altitude.



Full-scale solid rocket plume at simulated high altitude in AEDC's J-4 test cell.



Flight rocket plume at high altitude.

Titan IV Stage II LR-91 Engine Test Program

The Titan IV Stage II LR-91 engine test program was one of the most ambitious and successful rocket test programs ever conducted at AEDC. America's heavy lift launch capability hit a major snag when an LR-91 engine failed a nozzle qualification test under sea-level conditions in July 1995.

Exactly eight months from authorization to proceed, AEDC had installed a new hypergolic propellant system, reactivated its J-4 large simulated-altitude test facility, and successfully tested an LR-91 engine for 274 seconds, a new record for altitude testing an engine of that size. Not only did the nation regain its heavy lift launch capability with qualification of a new quartz phenolic nozzle, but it was the first AEDC test of a large liquid engine in nearly 20 years. The record was to stand for only 28 days as AEDC fired another LR-91 engine for 300 seconds.

The Aerojet LR-91 engine produces approximately 106,000 pounds of thrust. It is a pump-fed engine burning the hypergolic propellants Aerozine 50 and nitrogen tetroxide. The Air Force Space and Missile Systems Center (SMC) selected AEDC to conduct the nozzle qualification tests due to its unique capability to test large liquid engines for long duration under simulated-altitude conditions. Due to the size and complexity of the task to complete the J-4 facility modifications, AEDC entered into a teaming arrangement with SMC, Lockheed Martin Astronautics, TRW, Brown and Root and a host of smaller companies in a joint cooperative effort.

In both tests, AEDC met 100 percent of primary and secondary test objectives using a wide array of diagnostic instrumentation to verify the nozzle material withstood the full 300 second burn and to collect additional plume phenomenology and nozzle heating data. This instrumentation included high-speed video and movie cameras to verify nozzle structural integrity, infrared imaging to map nozzle thermal distributions and detect hot spots, and laser induced fluorescence to investigate propellant film cooling in the nozzle.

The Assistant Secretary of the Air Force for Acquisition, Arthur L. Money, expressed his appreciation in a letter to Gen. Henry Viccellio, then commander of Air Force Materiel Command, "We needed a Herculean effort to support our critical operational launch commitments and once again your people delivered. The combined AFMC/contractor team pulled together to keep the Titan flying. Their outstanding work in bringing a 35-year-old facility back on-line, while simultaneously integrating new water handling and hypergolic fuel systems to support both the Titan and EELV programs represents a truly amazing effort."

A Titan IV second stage engine fires in AEDC's J-4 Rocket Test Cell.

Pratt & Whitney RL-10B2 Test

AEDC recently completed three major "firsts" in testing Pratt & Whitney's RL-10B2 engine, an entry in the Evolved Expendable Launch Vehicle Program.

This was the first use of AEDC's new cryogenic propellant sytem and the first test of such a large nozzle extension under simulated altitude conditions, and the first demonstration of a two-test-per-week cycle time capability.

The Pratt & Whitney RL-10B2 is a liquid hydrogen/liquid oxygen fueled rocket engine producing a nominal thrust of 25,000 pounds. The test program included development and qualification testing of RL-10B2 engines with the improved nozzle extension. Test requirements included 250 second burn times and approximately 100,000 foot simulated altitudes.

The engine uses a new extendible carbon/carbon nozzle extension with a nominal area ratio of 285 to 1 to obtain the required performance. The high area ratio and fragility of the light-weight nozzle required the low cell and back pressures attainable using the unique AEDC exhaust capability.

To assess the improved performance of the new nozzle extension, accurate engine thrust measurement was a prime test objective. To satisfy this requirement, AEDC used a multi-component force thrust stand with a new in-place applied load calibration system.

The in-place calibration feature allows for a more accurate measurement by allowing for external "tare" forces inherent in cryogenic propellant feed systems connected to the engine.

Secondary test objectives included subjecting the engine to off-nominal conditions during start and steady-state operation and rapid relights as part of the development and qualification programs.

An AEDC engineer inspects the Pathfinder engine tested in the center's J-4 Rocket Test Cell . Following a $9.7 million reconfiguration and reactivation program, the center resumed testing of cryogenic liquid-propellant rocket engines.

An RL-10 engine with a nozzle extension is tested to verify performance.

Aging and Surveillance Test Programs

AEDC has actively supported Aging and Surveillance (A&S) testing of Minuteman and Peacekeeper ICBM propulsion systems at simulated altitude conditions since the late 1960s.

Until the activation of the J-6 Test Facility, most of this testing occurred in the J-5 Test Facility; however due to its size, the Peacekeeper Stage II was tested vertically in the J-4 Test Facility.

Activating J-6 allowed the consolidation of all solid rocket motor testing in one facility. J-6 is ideally suited for these tests due to its large size and capability to test detonable motors under simulated-altitude conditions.

From its activation, through September 1997 five Peacekeeper and seventeen Minuteman motors were tested in J-6 with 100 percent of the test objectives accomplished on each test.

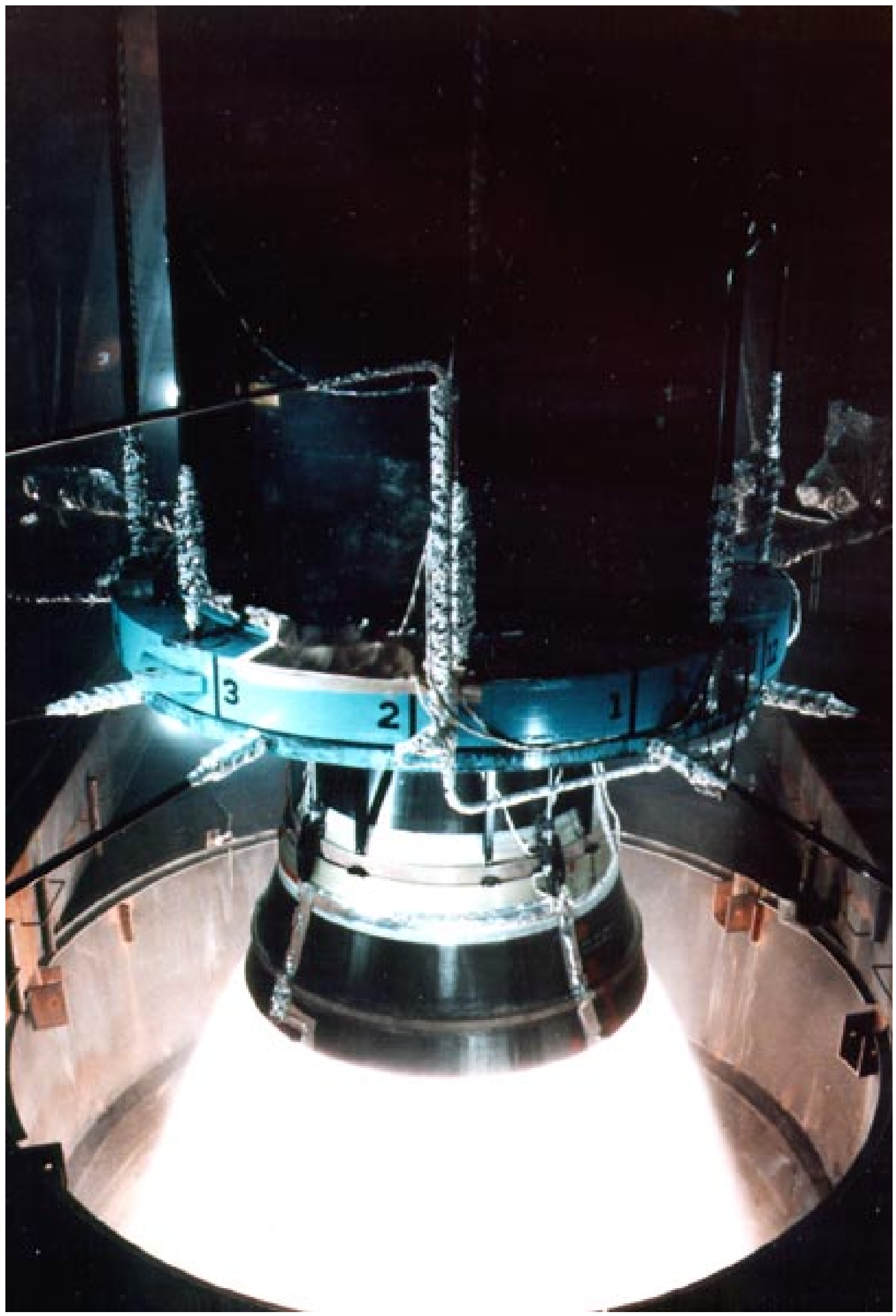
The Ogden Air Logistics Center (OGDEN-ALC), Hill AFB, Utah, manages the ICBM A&S Program. Their objectives are to identify any age-related degradation in motor or component performance and project the service life of the ICBM fleet.

AEDC supports OGDEN-ALC by testing the solid upper stage motors at simulated altitude conditions to provide the data necessary to accurately identify aging trends in system performance.

OGDEN-ALC selects test motors to support the A&S effort from the deployed operational system. Therefore, the motors being tested have been exposed to the operational (silo) environment and represent the most aged assets in the field.

AEDC also supports the A&S Minuteman and Peacekeeper post-boost propulsion systems testing. These are self-contained, prepackaged liquid bipropellant propulsion systems tested at simulated altitude conditions in the J-3 Test Facility. The objectives of these tests are the same as for the solid stages, to identify any age-related degradation in system performance and project the service life of the system.

In addition to simply providing test services, AEDC brings a suite of tools to help evaluate motor performance. These include database management and statistical analysis to identify aging trends as well as test tools including acoustic sensing to determine propellant burn rate regression, real-time radiography to assess motor internal status, and a host of computational models to aid in performance evaluation.



A 300,000-pound thrust Peacekeeper ICBM Stage II solid rocket motor is fired in J-4, the nation's largest altitude simulation rocket test cell.

AEDC Supports Minuteman III Propulsion Replacement Program (PRP)

The Minuteman III Propulsion Replacement Program (PRP), managed by the Ogden Air Logistics Center (OGDEN-ALC), will extend the service life of the three solid propellant stages through 2020. The PRP is composed of two phases: Technology Insertion and Remanufacture.

During Technology Insertion, changes are being incorporated into existing motor designs and processes to comply with environmental regulations and to correct known hardware problems. These design and process changes are demonstrated/verified by full-scale Change Verification Motor (CVM) tests and qualified by Qualification Motor (QM) tests. Production Quality Assurance (PQA) motor tests will verify specification compliance during the remanufacture phase.

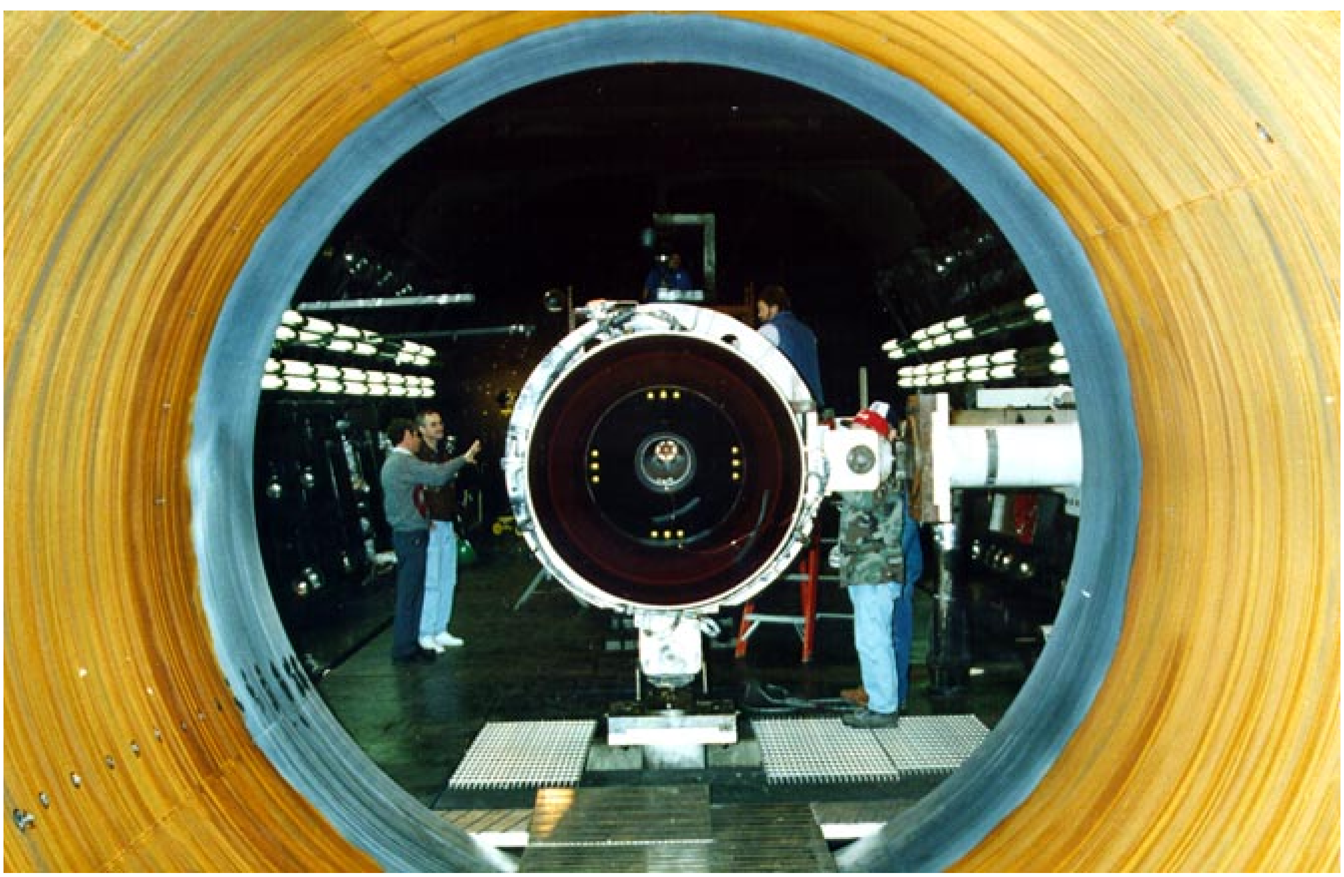
The CVM tests simulate the operating environment to evaluate the performance of the system and obtain data comparable to historical data. For these reasons, the second and third stage motors are tested at AEDC's J-6 Large Rocket Test Facility which allows the motors to be tested at a simulated altitude of up to 100,000 feet while gathering the necessary data to evaluate the component changes and overall system performance

In fiscal year 1996 there were two Stage II CVM tests. In fiscal 97 there were three stage II CVM tests and three stage III CVM tests. The CVM testing is planned to be completed in fiscal 98 with four Stage II and three Stage III tests. The first QM testing will begin in fiscal 99 with three Stage II and four Stage III tests and then be completed in fiscal year 2000 with three Stage II and four Stage III tests.

Test data is archived using AEDC's Test Project Archiving System, TPAS, system in a CD-ROM format. This allows all test plans, procedures, data, videos, and related documentation to be stored in a single location for easy retrieval.

To assist in maximizing useful information from these tests, AEDC has employed several advanced diagnostic tools.

These include high-speed video, acoustic sensing of propellant burn rates, and the use of real-time radiography (RTR) to visualize internal phenomena during the motor firing.



A Minuteman III rocket motor is installed in the J-6 Large Rocket Test Facility.

AEDC's Altitude Rocket Propulsion Test Facilities

AEDC has unique test capabilities for testing rocket systems with high performance, high area-ratio nozzles, and those requiring altitude start and restart, stage separation, and solid rocket motor spin testing.

The unique capabilities come from the physical size and configuration of our test facilities and their connection to the Engine Test Facility (ETF) exhaust plant. These facilities are the largest of their kind in the world and provide the only altitude test capability for medium to large liquid and solid rocket propulsion systems. AEDC facilities are characterized by:

The connection to the AEDC ETF Exhaust Plant, combined with the use of a unique close-coupled annular steam ejector, provides optimal means of attenuating potentially damaging facility pressure transients that occur during engine ignition and shutdown.

This unique configuration provides for the only safe test capability of rocket propulsion systems utilizing fragile, high performance (high area-ratio) nozzles.

Connection to the exhaust plant also allows for extended run times at altitude conditions required for many propulsion systems used in orbital transfer operations.

To better understand this, consider AEDC's simulated altitude rocket test facility's configuration and operation. First, the test cell is a cylindrical chamber that contains the test article at the required test conditions of pressure and temperature. In the cell, static restraint of the test article is provided by a full six-component force measurement system with an inplace calibration system for increased measurement accuracy. Maintaining the required test conditions requires the constant removal of the rocket's exhaust products as

(continued on next page)

Key Features

- Environmental cleanliness through exhaust handling measures
- Exhaust plant and close-coupled steam ejectors to simulate altitude conditions
- Accurate six-component thrust measurement
- Instrumentation and control systems

Complete test support infrastructure including:

- Fabrication and machine shops
- Clean rooms
- Radiographic inspection facility
- Instrumentation calibration labs
- Secure storage with explosive site approval
- Large high-speed computer data acquisition and processing systems
- Compatibility with an extensive array of diagnostic tools

Facility Summary

J-6 Horizonal Rocket Propulsion Development Simulated Altitude Facility.

The ETF exhaust plant removes the exhaust gas products from the test facility. This function provides for a relatively low simulated altitude pressure. The exhaust plant performance is augmented and extended by using a diffuser system located immediately behind and in close proximity to all the rocket engine nozzle exit.

During engine operation the diffuser aspirates the test cell gases in a complicated flow entrainment and missing process while exchanging kinetic energy for pressure by flow deceleration. This is even further enhanced by a steam ejector-diffuser immediately downstream of the engine diffuser exit plane. Using an annular type steam ejector located close to the rocket engine nozzle exit is an optimum configuration unique to AEDC's rocket test facilities.

The steam ejector-diffuser system provides two important functions. Before rocket engine iginition, the steam ejector-diffuser operates alone and helps establish the proper test cell pressure for the test objectives.

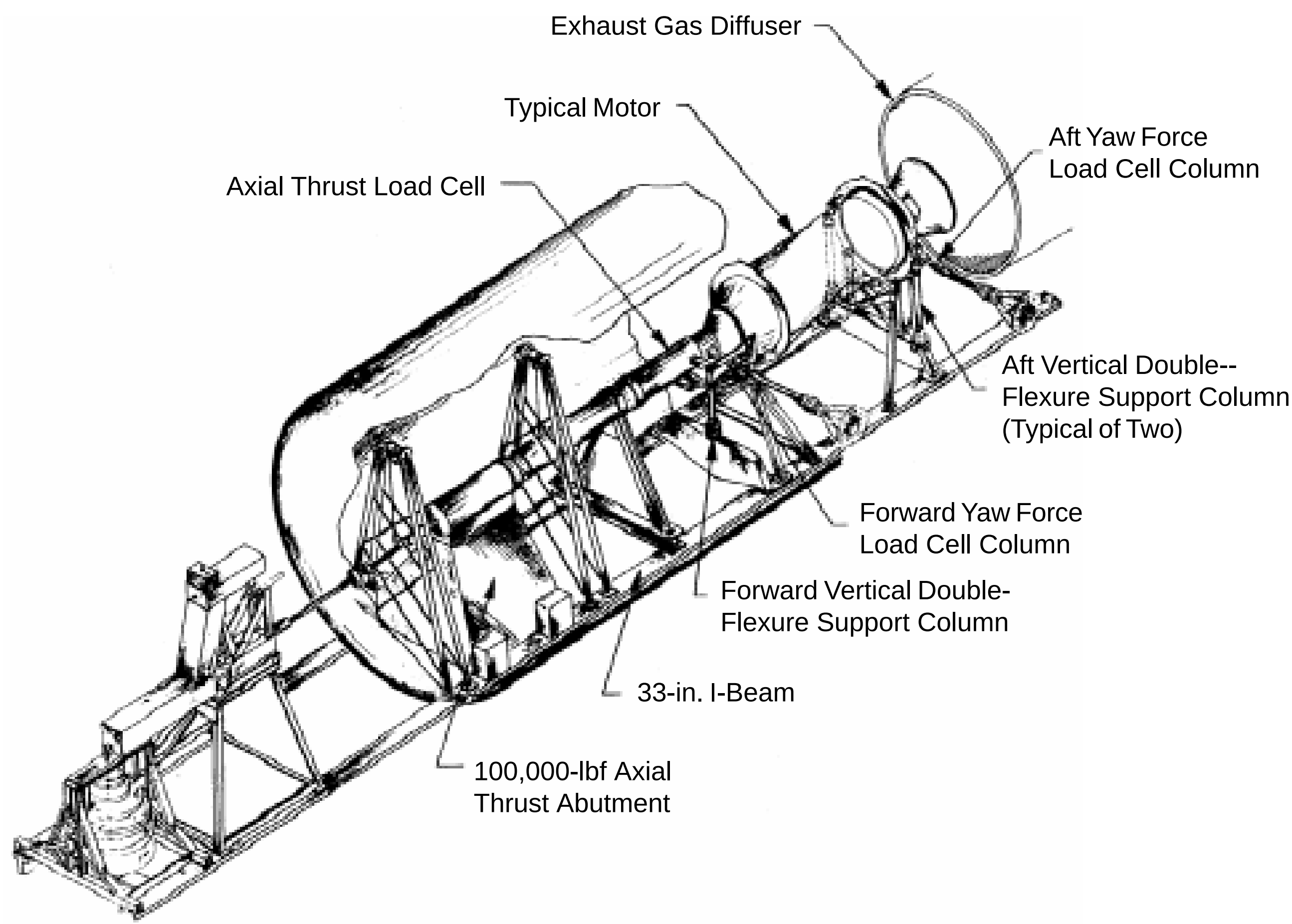
After rocket engine ignition, test cell pumping responsibility is transferred to the rocket engine ejector-diffuser system allowing the steam ejector to be "throttled back." Upon engine shutdown, the process is reversed and a transition in the pumping and pressure recovery responsbility is handed back to the steam ejector-diffuser system alone.

Operating in this manner, the team ejector-diffuser system performs like a quick response pneumatic check valve, that minimizes the test cell pressure transients during engine ignition and shutdown. The steam ejector isolates the test cell from the spray chamber and allows a controlled pressure equalization process between the two chambers.

Rocket test operations require the removal of hazardous exhaust products from the flow before reaching the exhaust plant. The importance of this exhaust cleaning process is becoming more evident as environmental regulations become more stringent. The cleaning process involves scrubbing the exhaust with large amounts of cooling water which removes all the condensable species from the rocket exhaust. This cooling water treatment also greatly aids exhaust gas pumping by removing the large quantity of water vapor produced by the steam ejector.

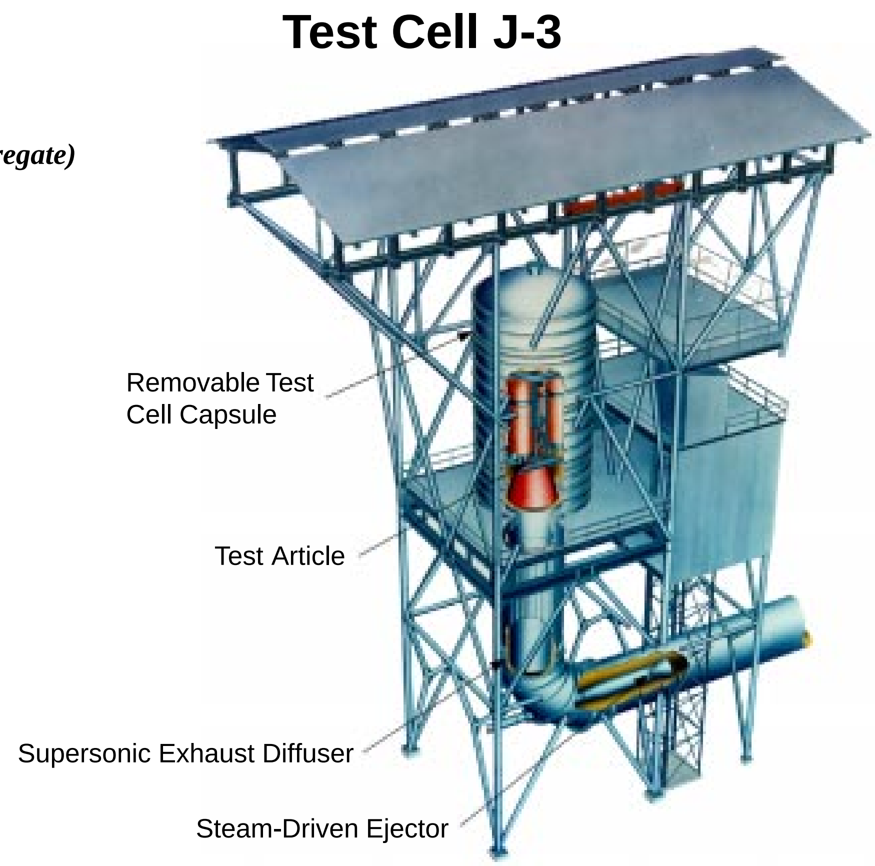
The environmental treatment is concluded when the cooling water is released in an approved, passive neutralization process back to the AEDC reservoir.

Multicomponent Thrust Measuring System



Rocket Development Test Cell J-3

- ***Vertical orientation***
- ***125,000 ft. simulated altitude***
- ***17 ft. diameter x 40 ft. high***
- ***200,000 lb. max. thrust***
- ***80,000 data samples/second (aggregate)***



Rocket Development Test Cell J-3 is a vertical test cell designed to test engines with up to 200,000 pounds thrust at a simulated altitude up to 125,000 feet. However, current safety restrictions limit testing to engines with less than 4,000 pounds of class 1.3 propellant. In addition to simulated altitude control, J-3 is equipped with liquid nitrogen-cooled panels for simulating low-temperature (20° to 130°F) environments in addition to low pressures. The J-3 test cell capsule has an internal diameter of 17 feet and a height of 40 feet.

The facility is capable of testing stand-alone engines and fully-integrated liquid or solid stages, such as ICBM post-boost stages. A recent improvement to J-3 is the addition of a storable propellant feed system which allows testing of small storable engines with up to 1,000 pounds per foot of thrust.

Unique test capabilities include: Extremely long duration altitude (mission duty cycle) tests; tests of high-area-ratio nozzles (exit diameters up to 100 inches); and altitude performance, ignition performance, nozzle development, stage separation, heat transfer, vibration, dynamics, failure analysis (propellant extinguished), and post test heat-soak testing.

Some of the engines that have been tested in J-3 are the Titan Improved Transtage, AJ10-137 (Apollo Service Module), XLR-91 (Titan), Inertial Upper Stage, and Minuteman, Peacekeeper, and Small ICBM post-boost propulsion systems.

The rocket motor for the Apollo Service Module is shown being installed in rocket test cell J-3.